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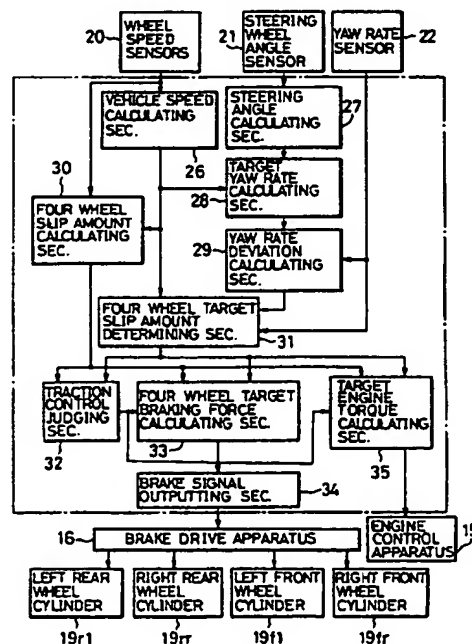
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(54) Traction control in a four-wheel drive vehicle

(57) Traction control in a four-wheel drive vehicle involves wheel braking and reduction of engine torque. A target slip for each wheel is determined at 31 in dependence on a reference slip, vehicle speed, actual yaw rate, and yaw rate deviation. When traction control is needed, as determined in judging section 32 by a comparison of the actual and target slip for each wheel, a signal is outputted to calculating means 33 which produces a braking force, according to the difference between the target slip and the actual slip, for each wheel and to calculating means 35 which produces a signal to the engine control apparatus 15 to reduce engine torque. The reference slip is that achieved by a wheel when in a straight running condition or in a neutral steer condition when executing a turn.

FIG. 1



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FIG. 1

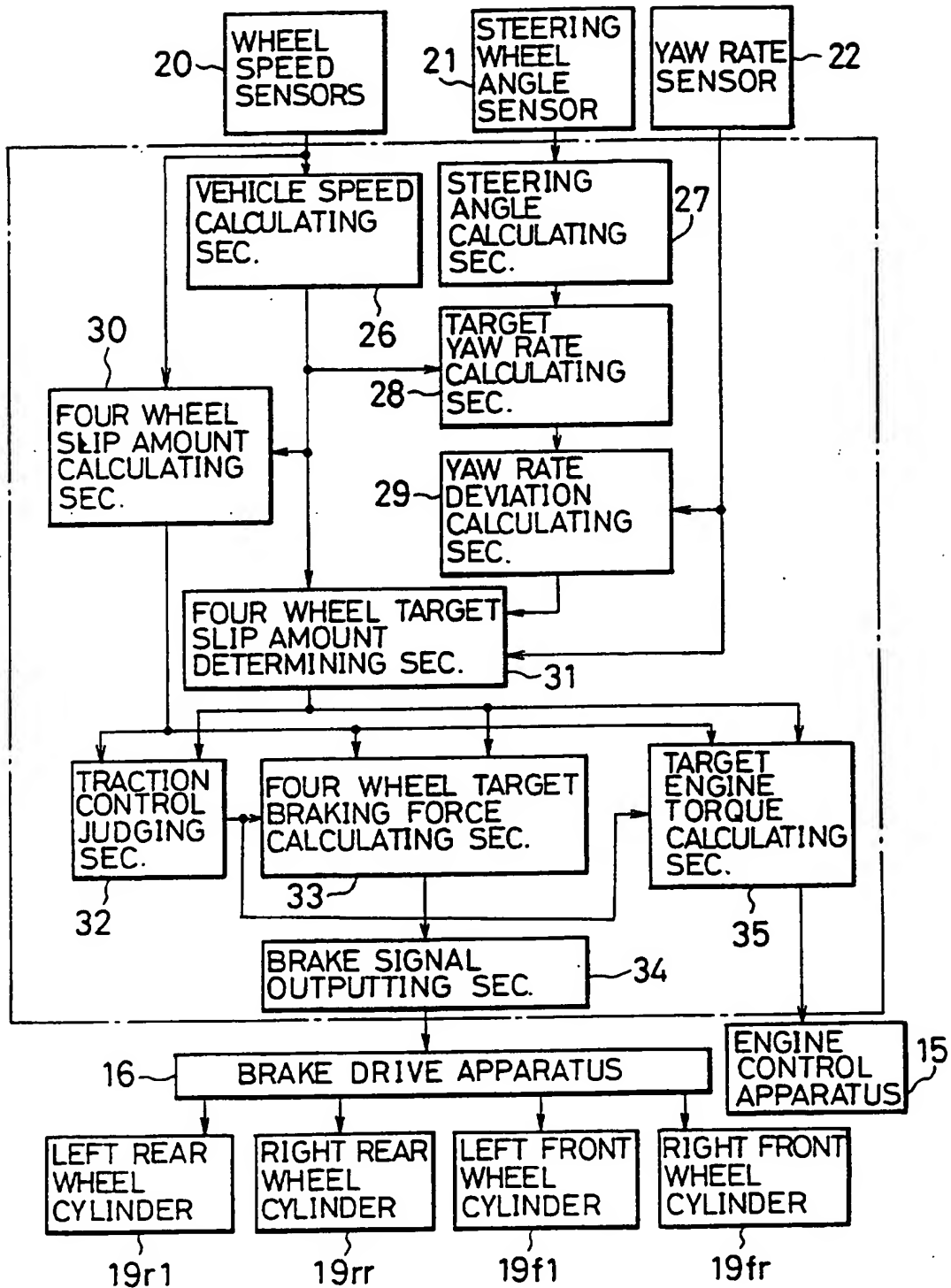


FIG. 2

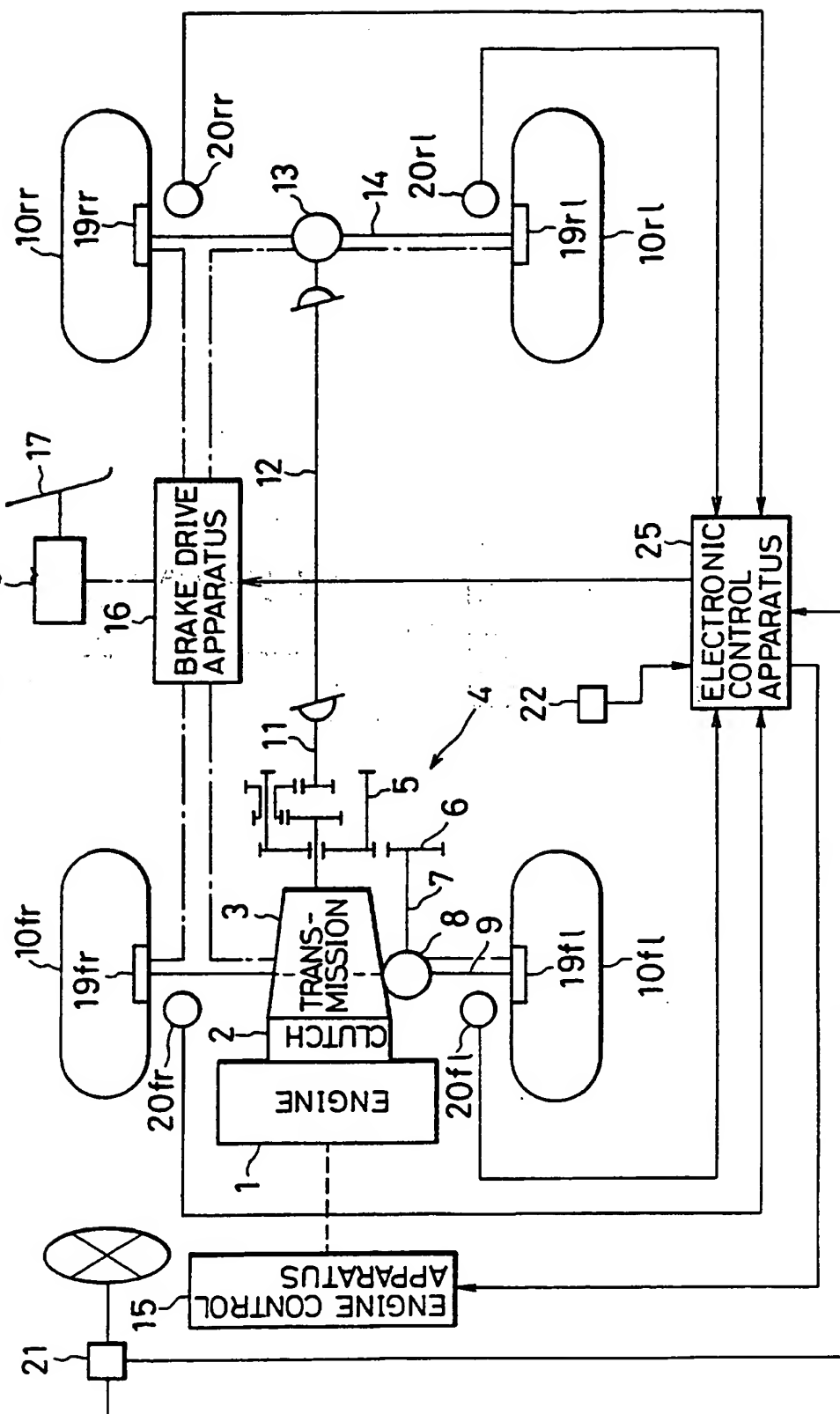


FIG. 3a

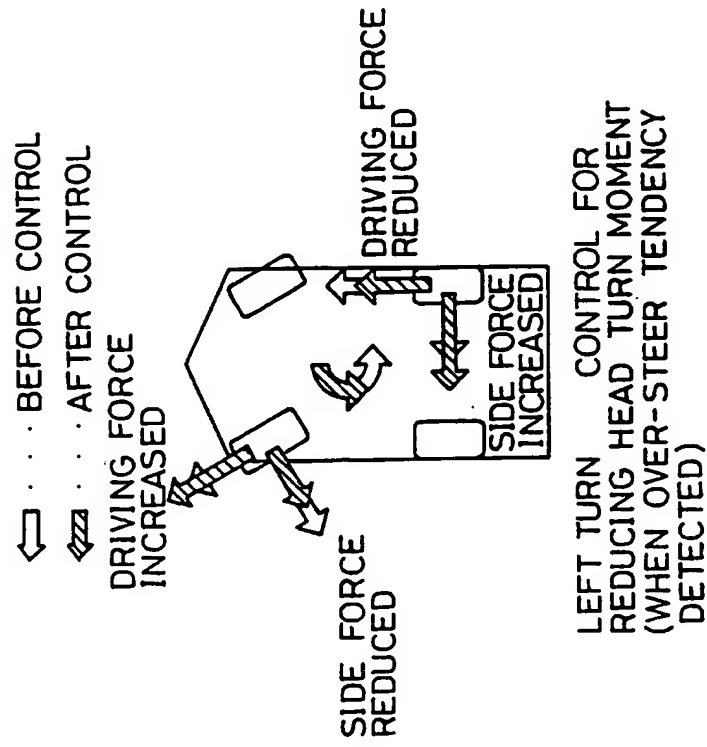
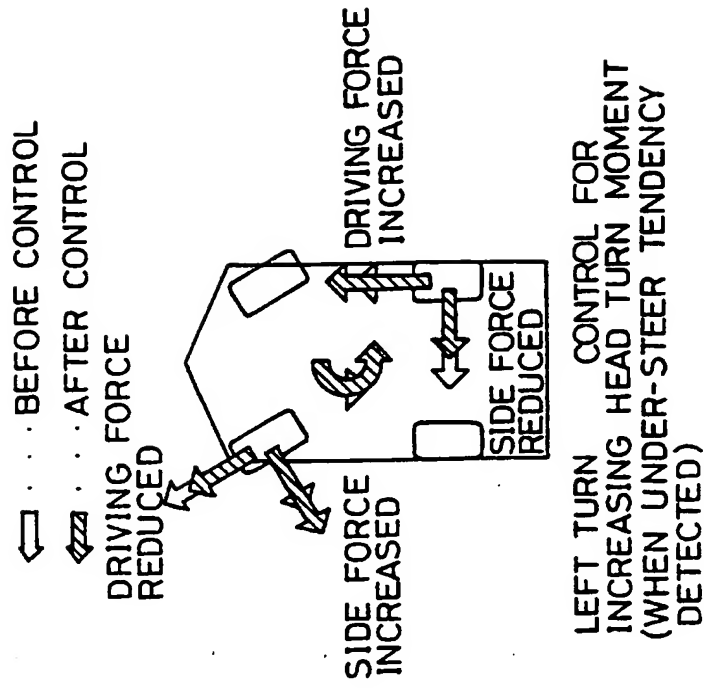


FIG. 3b



4/7

FIG. 4

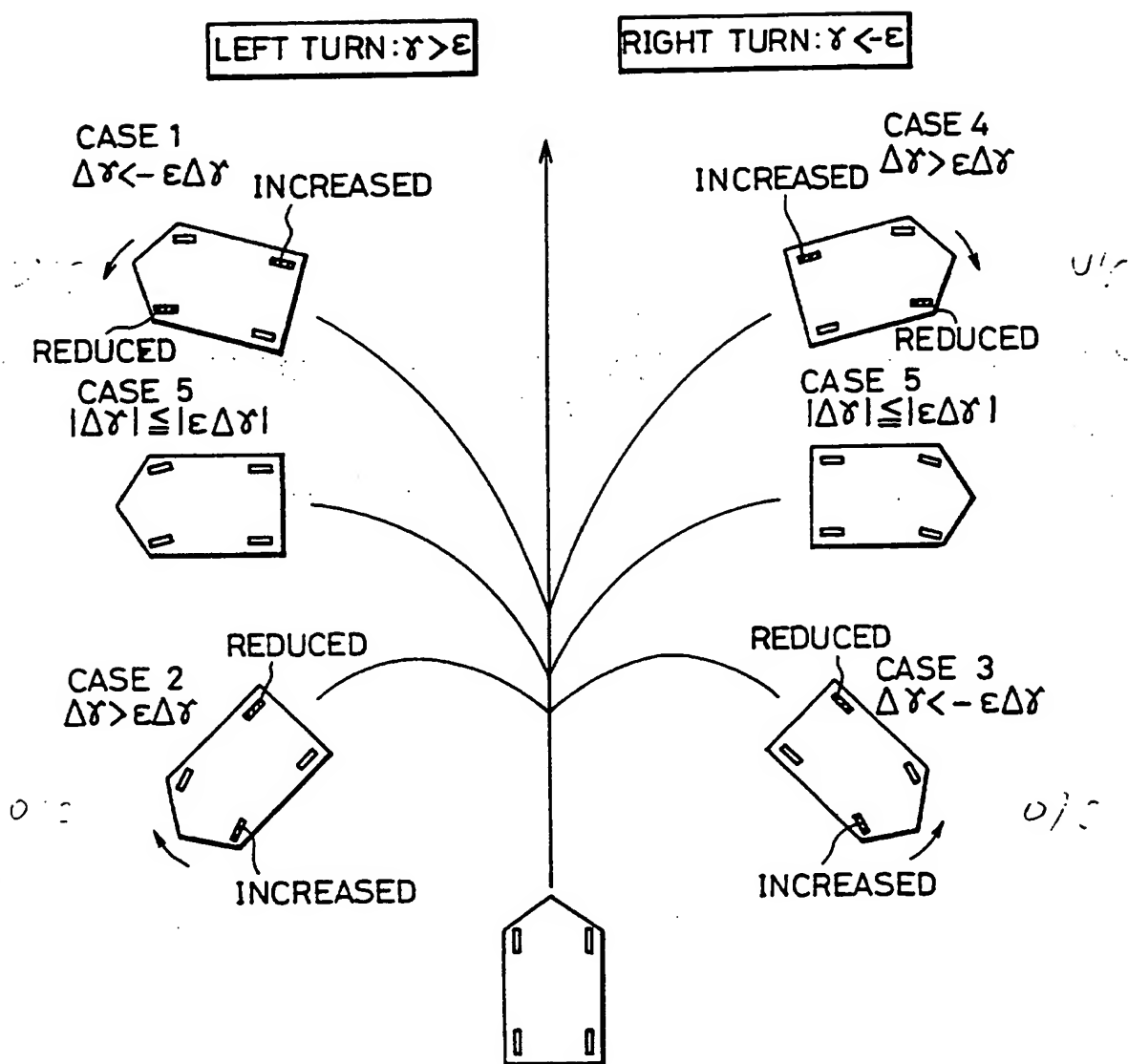


FIG. 5a

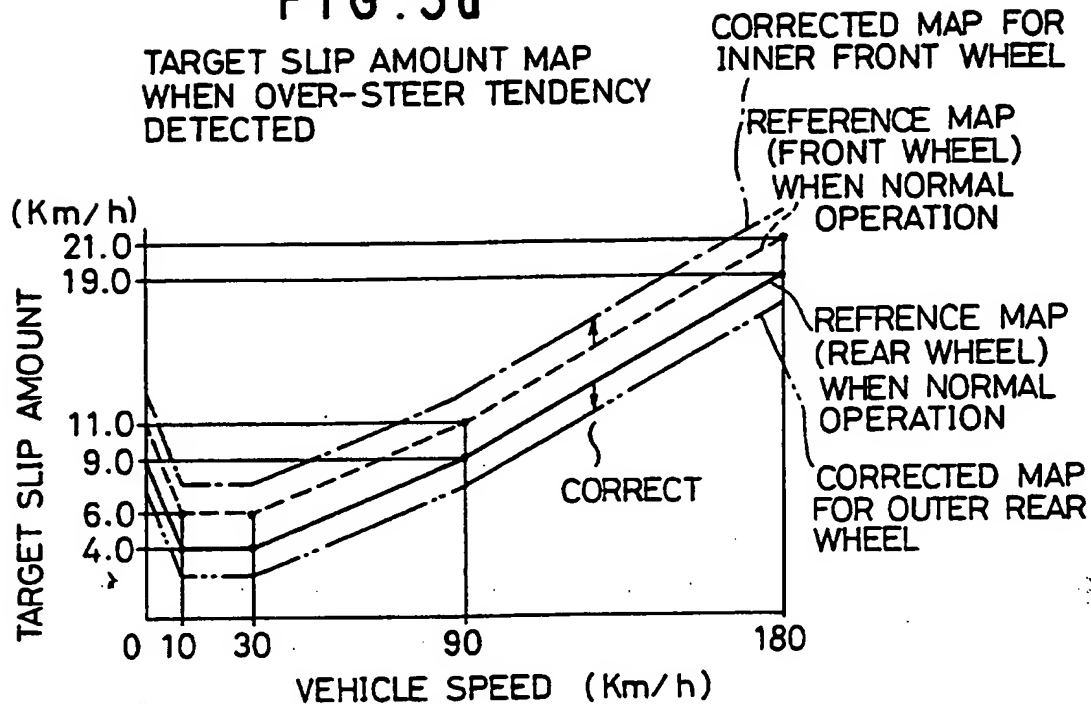
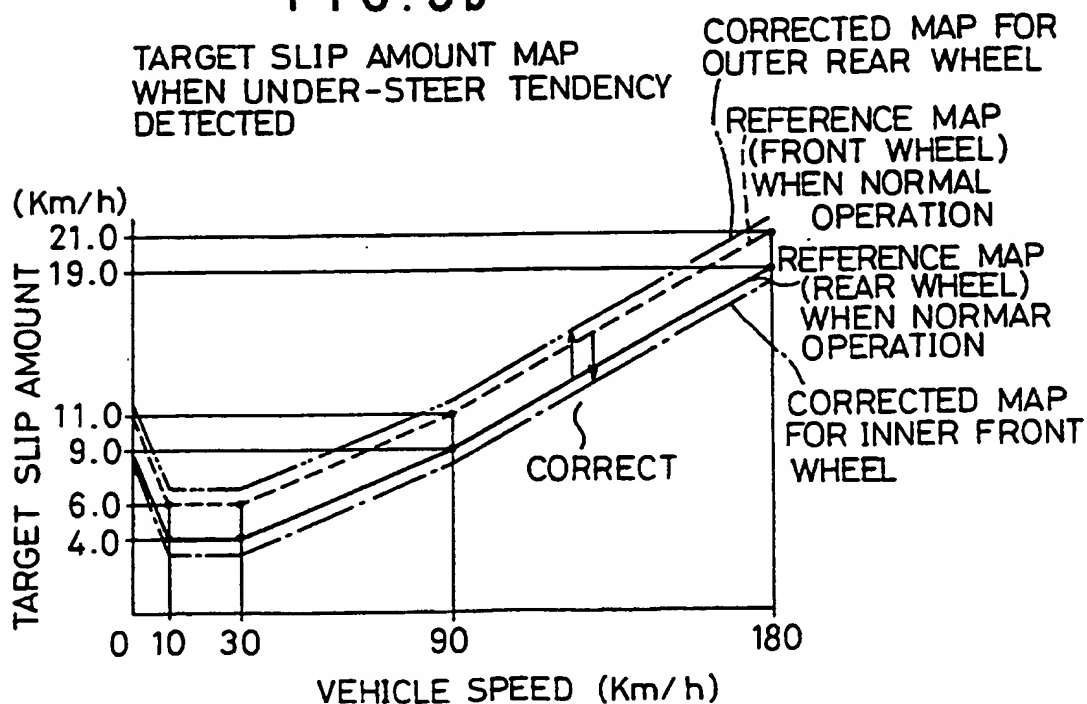
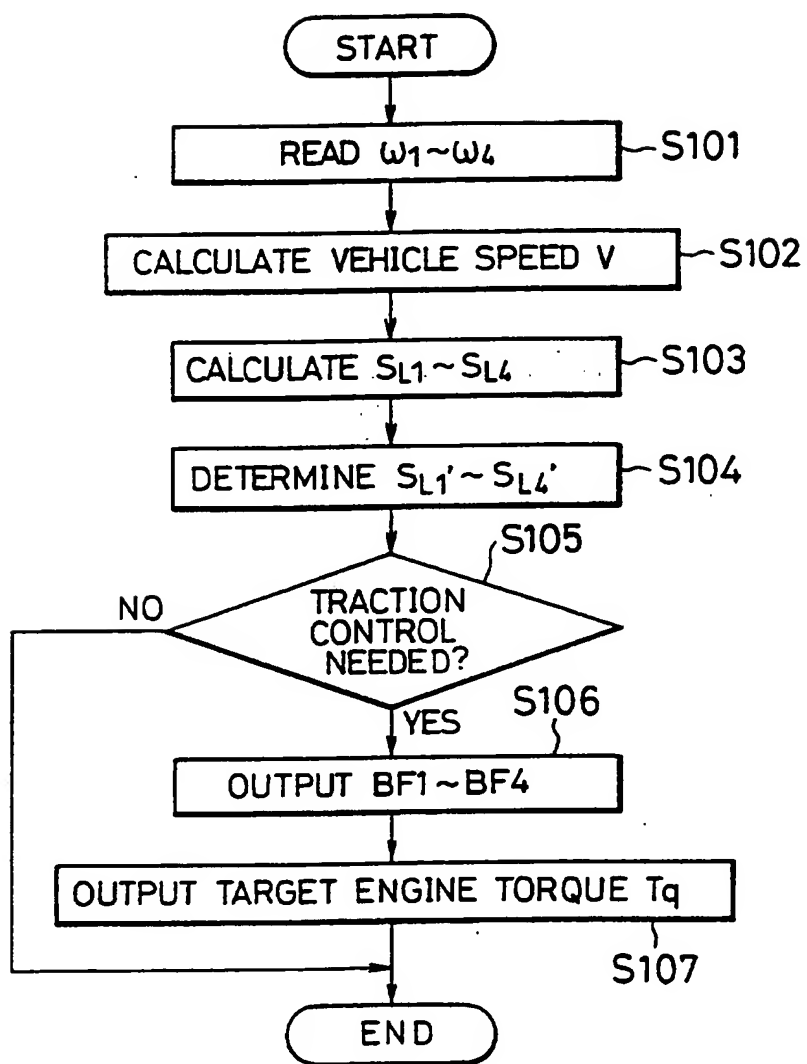


FIG. 5b



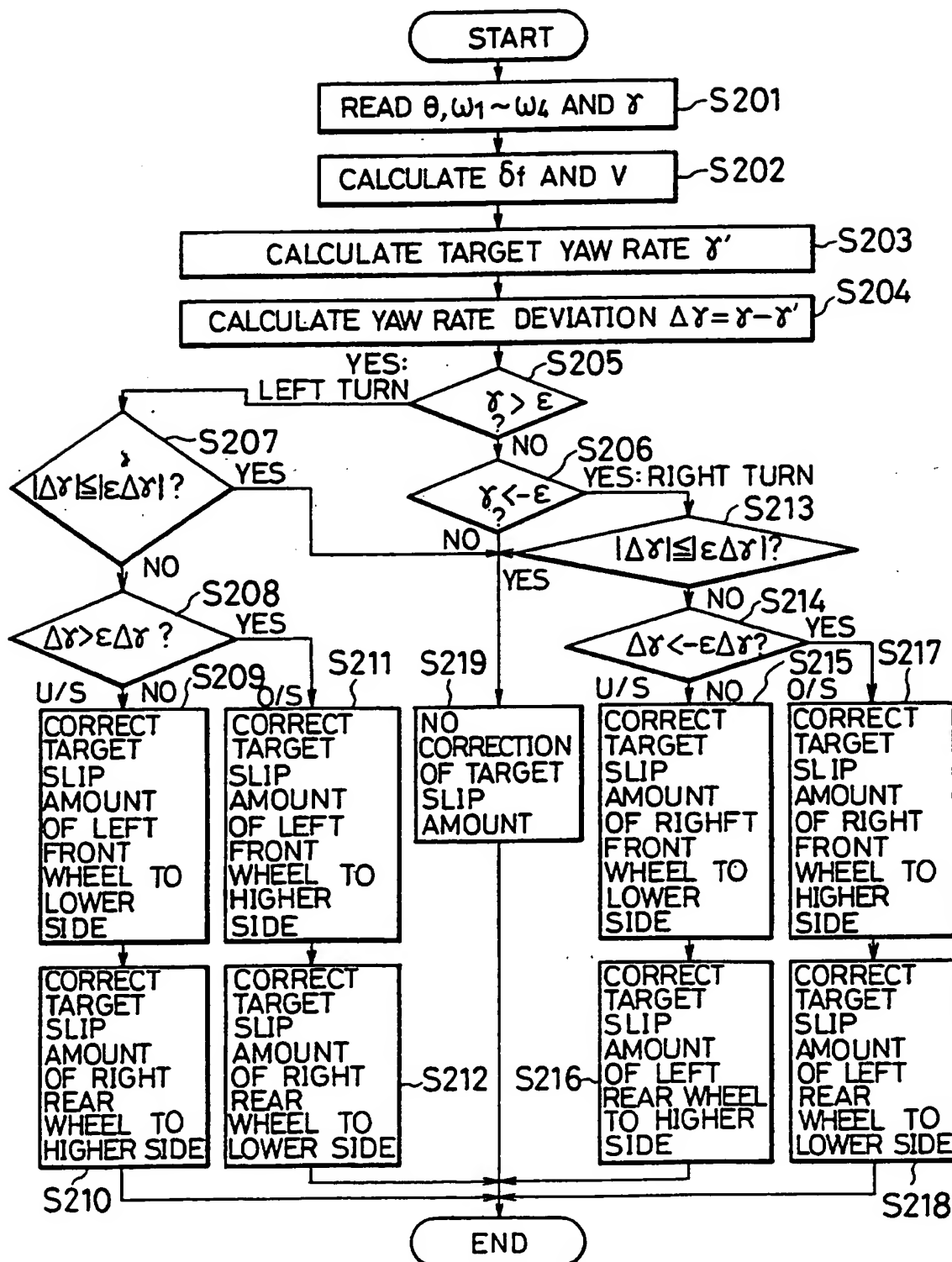
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FIG. 6



7/7

FIG. 7



- 1 -

DESCRIPTIONTRACTION CONTROL SYSTEM AND METHODFOR FOUR WHEEL DRIVE VEHICLE

The present invention relates to a traction control system and method for a 4-wheel drive vehicle and more particularly to a traction control system and method ensuring driving stability by means of independently controlling driving forces of the four wheels.

In recent years, due to an increasing concern about vehicle safety, many techniques for safe driving have been developed. There are several proposed technologies in which when a vehicle turns corners an optimally controlled braking force is applied to the wheels based on vehicle driving conditions data for accomplishing stable and smooth cornering of the vehicle.

For example, Japanese Unexamined Patent Application Toku-Kai-Hei 2-70561 discloses a braking force control apparatus for controlling braking force on the basis of a yaw rate or an angular velocity of yawing, i.e., a rotational motion about a vertical axis passing through a centre of gravity of the vehicle. In this technology, it is judged whether the vehicle is turning in an under-steer condition or

in an over-steer condition with respect to a target yaw rate by comparing an actual yaw rate with the target yaw rate and if the vehicle is in under-steer, a braking force is applied to inner wheels (wheels on the side of a turning centre) to correct under-steer such that a deviation of the actual yaw rate from the target yaw rate is minimized and if the vehicle is in over-steer, braking force is applied to outer wheels (wheels on the opposite side of a turning centre) to correct over-steer.

A traction control introduced onto a four-wheel drive vehicle enables the vehicle to have a good maneuverability on a road with a surface having low friction coefficient and vehicle stability in a marginal zone. Here, it is considered that if the aforementioned braking force control is introduced to a four-wheel drive vehicle incorporating the traction control, the vehicle stability may be further improved.

However, in case of a vehicle having both traction control and braking force control, there are problems such as nullifying the effect or adversely spoiling the traction performance due to a phenomenon, for example, that a wheel under traction control restores grip when the braking force control is applied to that wheel.

The present invention is intended to obviate the

abovementioned problems of the prior art and it is an object of the present invention to provide a traction control system capable of determining a target slip amount for each wheel so as to prevent excessive tyre slip, resulting in enhancement of vehicle stability during cornering.

In accordance with one aspect, the present invention comprises: an engine control apparatus for controlling an output torque of an engine, four wheels including front and rear wheels, a wheel cylinder for each of the four wheels, wheel speed detecting means for detecting a wheel speed of each wheel; vehicle speed detecting means for detecting a vehicle speed; steering angle detecting means for detecting a steering angle; and a brake drive apparatus for independently and automatically applying brake pressure to the wheel cylinders, yaw rate detecting means for detecting an actual yaw rate of the vehicle, target yaw rate calculating means for calculating a target yaw rate of the vehicle based on the vehicle speed and the steering angle, yaw rate deviation calculating means for calculating a yaw rate deviation by subtracting the target yaw rate from the actual yaw rate, slip amount calculating means for calculating an actual slip amount for each wheel based on the vehicle speed and the wheel speed, storing means for memorizing a reference slip amount for each of the front and rear wheels respectively, target slip amount determining means for independently determining a target slip amount for each wheel based on the reference slip amount, the

vehicle speed, the actual yaw rate and the yaw rate deviation, traction control judging means for judging whether or not a traction control is needed for each wheel based on the comparison of the slip amount with the target slip amount and for outputting a traction control signal so as to execute the traction control if it is judged that any one of the four wheels needs the traction control, target braking force calculating means responsive to the traction control signal for calculating a target brake pressure based on the actual slip amount and the target slip amount and for outputting the target brake pressure to the brake drive apparatus so as to apply the target brake pressure to the wheel cylinder of the wheel needing the traction control, and target engine torque calculating means responsive to the traction control signal for calculating a target engine torque based on the actual slip amount and the target slip amount and for outputting the target engine torque to the engine control apparatus so as to reduce the output torque of the engine.

By way of example only, a specific embodiment of the present invention will now be described, with reference to the accompanying drawings, in which:-

Fig. 1 is a functional block diagram of a traction control system according to an embodiment of the present invention;

Fig. 2 is a schematic diagram of a traction control system according to an embodiment of the present invention;

Fig. 3 is a drawing for explaining how to control a head turn moment according to an embodiment of the present invention;

Fig. 4 is a drawing showing an operation of a vehicle under the traction control according to an embodiment of the present invention;

Fig. 5 is a diagram showing an example of a map for determining a target slip amount according to an embodiment of the present invention;

Fig. 6 is a flowchart showing a traction control according to an embodiment of the present invention; and

Fig. 7 is a flowchart for determining a target slip amount according to an embodiment of the present invention.

Referring now to Fig. 2, numeral 1 denotes an engine to which a centre differential 4 is connected through a clutch 2 and a transmission 3. The centre differential 4 has a complex planetary gear set capable of selectively distributing torque equally or unequally. A pinion shaft 5 of the centre differential 4 is connected with a left front wheel 10fl and a right front wheel 10fr through a reduction gear 6, a front drive shaft 7, a front differential 8 and a front axle 9 and its output shaft 11 is connected with a left rear wheel 10rl and a right rear wheel 10rr through a propel-

ler shaft 12, a rear differential 13 and a rear axle 14 so as to enable a four-wheel drive.

The engine 1 is controlled by an engine control apparatus 15 which performs a fuel injection control, a throttle control, an ignition timing control, a cylinder suspending control, a charge pressure control and other controls. This engine control apparatus also controls the engine 1 so as to increase or decrease its output.

On the other hand, numeral 16 denotes a brake drive apparatus to which a brake pedal 17 operated by a vehicle driver and a master cylinder 18 are connected. When the vehicle driver depresses the brake pedal 17, brake pressure is supplied from the master cylinder 18 to each of wheel cylinders, 19_{fl} for a left front wheel, 19_{fr} for a right front wheel, 19_{rl} for a left rear wheel and 19_{rr} for a right rear wheel through the brake drive apparatus 16 to apply brakes to four wheels, a left front wheel 10_{fl} , a right front wheel 10_{fr} , a left rear wheel 10_{rl} and a right rear wheel 10_{rr} .

The brake drive apparatus 16 is a hydraulic unit comprising a pressure source, pressure reducing valves, pressure increasing valves and the like for feeding brake pressure independently to each wheel cylinder, 19_{fl} , 19_{fr} , 19_{rl} and 19_{rr} , according to input signals.

The wheel speeds ω_1 , ω_2 , ω_3 and ω_4 of four wheels are detected independently for each of four wheels

10_{fl} , 10_{fr} , 10_{rl} , 10_{rr} respectively by wheel speed sensors, 20_{fl} for the left front wheel, 20_{fr} for the right front wheel, 20_{rl} for the left rear wheel and 20_{rr} for the right rear wheel. Further, a steering wheel angle sensor 21 is disposed at the steering wheel section to detect the rotational angle θ of the steering wheel.

Further, numeral 25 denotes an electronic control apparatus composed of a micro-computer and its peripheral circuits, to which the wheel speed sensors 20_{fl} , 20_{fr} , 20_{rl} and 20_{rr} , the steering wheel angle sensor 21 and a yaw rate sensor 22 composed of acceleration sensors for detecting an actual yaw rate and from which a drive signal is outputted to the brake drive apparatus 16. The signal from the yaw rate sensor 22 is inputted to the electronic control apparatus 25 through a low-pass filter of 7 Hz, for example.

As shown in Fig. 1, the electronic control apparatus 25 comprises a vehicle speed calculating section 26, a steering angle calculating section 27, a target yaw rate calculating section 28, a yaw rate deviation calculating section 29, a four wheel slip amount calculating section 30, a four wheel target slip amount determining section 31, a traction control judging section 32, a four wheel target braking force calculating section 33, a brake signal outputting section 34 and a target engine torque calculating section 35.

The vehicle speed calculating section 26 obtains a

vehicle speed V by calculating based on wheel speeds $\omega_1, \omega_2, \omega_3, \omega_4$ derived from the wheel speed sensors 20fl, 20fr, 20rl, 20rr respectively according to a predetermined formula (for example averaging speed signals from the wheel speed sensors 20_{fl}, 20_{fr}, 20_{rl} and 20_{rr}) and outputs the calculated vehicle speed V to the target yaw rate calculating section 28, the four wheel slip amount calculating section 30 and the four wheel target slip amount determining section 31.

Further, the steering angle calculating section 27 calculates an actual steering angle $\delta f (= \theta / N)$ by dividing a steering angle θ derived from the steering angle sensor 21 by a steering gear ratio N and outputs the actual steering angle δf to the target yaw rate calculating section 28.

The target yaw rate calculating section 28 calculates a target yaw rate r' based on the vehicle speed V derived from the vehicle speed calculating section 26, the actual steering angle δf derived from the steering angle calculating section 27, taking a delay of response of the system into consideration.

The target yaw rate r' is calculated according to the following formula:

$$r' = [1 / (1 + T \cdot s)] \cdot G_{r \delta f} (0) \cdot \delta f \quad \dots \dots \dots (1)$$

where T is a time constant; s is a Laplacean. $G_{r \delta f} (0)$ is a value of yaw rate (yaw rate gain) with respect to an actual steering angle δf when the vehicle turns around a fixed circle. The target yaw rate gain $G_{r \delta f}$ is calculated accord-

ing to the following formula:

$$G_{\gamma \delta f}(0) = 1 / (1 + A_0 \cdot V^2) \cdot V / L \quad \text{..... (2)}$$

where L is a wheelbase of the vehicle; A_0 is a stability factor determined by vehicle specifications. Further, the stability factor A_0 is obtained according to the following formula:

$$A_0 = [-m \cdot (L_f \cdot CP_f - L_r \cdot CP_r)] / (L^2 \cdot L_2 \cdot CP_f \cdot CP_r) \quad \text{..... (3)}$$

where m is a vehicle weight; L_f is a distance between a front axle and a centre of gravity; L_r is a distance between a rear axle and a centre of gravity; CP_f is a front equivalent cornering power; CP_r is a rear equivalent cornering power. Further, the above formula (1) is an expression in which a delay of response of the vehicle expressed in the second order is approximated to the one expressed in the first order and the time constant T is obtained from the following formula:

$$T = m \cdot L_f \cdot V / 2 \cdot L \cdot CP_r \quad \text{..... (4)}$$

The yaw rate deviation calculating section 29 calculates a yaw rate deviation $\Delta \gamma$ ($= \gamma - \gamma'$) by subtracting the target yaw rate γ' outputted from the target yaw rate calculating section 28 from the actual yaw rate γ detected by the yaw rate sensor 22 and outputs this yaw rate deviation $\Delta \gamma$ to the four wheel target slip amount determining section 31.

The four wheel slip amount calculating section 30

calculates an actual slip amount of a wheel (a slip amount S_{L1} for the left front wheel, a slip amount S_{L2} for the right front wheel, a slip amount S_{L3} for the left rear wheel and a slip amount S_{L4} for the right rear wheel) based on the wheel speed ω_1 , ω_2 , ω_3 and ω_4 derived from the wheel speed sensor 20 (20_{fl} , 20_{fr} , 20_{rl} and 20_{rr}) and the vehicle speed V and outputs the actual slip amount to the traction control judging section 32, the four wheel target braking force calculating section 33 and the target engine torque calculating section 35. The slip amount (S_{L1} , S_{L2} , S_{L3} and S_{L4}) is obtained by subtracting the vehicle speed V from the wheel speed (ω_1 , ω_2 , ω_3 and ω_4).

$$S_{L1} = \omega_1 - V \quad \dots\dots (5)$$

$$S_{L2} = \omega_2 - V \quad \dots\dots (6)$$

$$S_{L3} = \omega_3 - V \quad \dots\dots (7)$$

$$S_{L4} = \omega_4 - V \quad \dots\dots (8)$$

The four wheel target slip amount determining section 31 determines, based on the vehicle speed V by referring to target slip amount maps which will be described hereinafter, a necessary target slip amount for each of the four wheels (S_{L1}' for the left front wheel, S_{L2}' for the right front wheel, S_{L3}' for the left rear wheel and S_{L4}' for the right rear wheel) independently and outputs the target slip amount to the traction control judging section 32, the four wheel target braking force calculating section 33 and the target engine torque calculating section 35.

The target slip amount is determined by referring to a map shown in Fig. 5a or Fig. 5b according to the vehicle running condition. First, a reference slip amount is plotted as a function of the vehicle speed with respect to the vehicle being operated roughly in a straight running condition or turning in a roughly neutral steer condition. The reference slip amount is established for each of front and rear wheels. When the target slip amount is read from the map, the above reference slip amount is corrected according to a process described hereinafter and this corrected reference slip amount provides a target slip amount when the traction control is carried out.

When the vehicle turns with a small turning circle at very low speeds, the wheel speeds ω_1 , ω_2 , ω_3 , ω_4 may make a relatively large difference. Further, in this condition, an output of the magnetic pick-up of the wheel speed sensor 20 (20_{fl} , 20_{fr} , 20_{rl} and 20_{rr}) may be low in voltage. Under these conditions, it is desirable to determine the target slip amounts on the large side, taking an adverse effect on precision into consideration. Further, the target slip amount is established such that it has a constant small value at low speeds and subsequently it becomes large as the vehicle speed V increases at intermediate and higher speeds.

Further, in order to enhance stability against spin of the vehicle during the traction control, the target slip amounts of rear wheels S_{L3}' , S_{L4}' (drawn in a solid

(line) are determined so as to be lower than those of the front wheels S_{L1}' , S_{L2}' (drawn in a broken line).

The reference slip amounts are corrected based on the actual yaw rate r and the yaw rate deviation Δr according to the program described as follows.

As shown in Fig. 3a, when it is detected that the vehicle makes a left turn and is in an over-steer tendency, the head turn moment can be reduced by increasing the driving force of the left front wheel for reducing the side force thereof and by decreasing the driving force of the right rear wheel for increasing the side force thereof. That is, in the map of the target slip amount, this can be accomplished by correcting the slip amount of the left front wheel to the higher side and the slip amount of the right rear wheel to the lower side. Further, as shown in Fig. 3b, when it is detected that the vehicle makes a left turn and is in an under-steer tendency, the head turn moment can be increased by decreasing the driving force of the left front wheel for increasing the side force thereof and by increasing the driving force of the right rear wheel for reducing the side force thereof. That is, this can be accomplished by correcting the slip amount of the left front wheel to the lower side and the slip amount of the right rear wheel to the higher side.

The corrections of the map of the target slip amount have following five selections (refer to Fig. 4).

Signs of the yaw rate c and the target yaw rate c' are both assigned to plus (+) with respect to a left turn and to minus (-) with respect to a right turn.

Case 1. The target slip amount of the left front wheel is reduced as if moving from broken line to one-dot chain line in Fig. 5b and the target slip amount of the right rear wheel is increased as if moving from solid line to two-dot chain line in Fig. 5b, when $\gamma > \varepsilon$ and $\Delta\gamma < -\varepsilon\Delta\gamma$, i.e., the vehicle is turning to the left and is in an under-steer tendency with respect to the target yaw rate γ' ;

Case 2. The target slip amount of the left front wheel is increased as if moving from broken line to one-dot chain line in Fig. 5a and the target slip amount of the right rear wheel is decreased as if moving from solid line to two-dot chain line in Fig. 5a, when $\gamma > \varepsilon$ and $\Delta\gamma > \varepsilon\Delta\gamma$, i.e., the vehicle is turning to the left and is in an over-steer tendency with respect to the target yaw rate γ' ;

Case 3. The target slip amount of the right front wheel is increased as if moving from broken line to one-dot chain line in Fig. 5a and the target slip amount of the left rear wheel is reduced as if moving from solid line to two-dot chain line in Fig. 5a, when $\gamma < \varepsilon$ and $\Delta\gamma < -\varepsilon\Delta\gamma$, i.e., the vehicle is turning to the right and is in an over-steer tendency with respect to the target yaw rate γ' ;

Case 4. The target slip amount of the right front wheel is reduced as if moving from broken line to one-dot

chain line in Fig. 5b and the target slip amount of the right rear wheel is increased as if moving from solid line to two-dot chain line in Fig. 5b, when $r < \varepsilon$ and $\Delta r > \varepsilon \Delta r$, i.e., the vehicle is turning to the right and is in an under-steer tendency with respect to the target yaw rate r' ; and

Case 5. No correction is made, when $|r| < |\varepsilon|$, i.e., the vehicle is almost in a straight running condition, or $|\Delta r| \leq |\varepsilon \Delta r|$, i.e., the vehicle is in an almost neutral-steer condition; where ε and $\varepsilon \Delta r$ are positive values which are nearly equal to zero and these are predetermined through other means such as experiments or calculations.

Thus, for each case the correction of the target slip amounts is made and then for each wheel the target slip amount (S_{L1}' , S_{L2}' , S_{L3}' and S_{L4}') is determined independently with reference to the map for the target slip amount determination according to the vehicle speed V .

In this embodiment, the correction of the slip amount is made for both front and rear wheels, however, the correction may be made for the front or rear wheel only, if the obtained yaw moment is sufficiently large.

In the traction control judging section 32, the actual slip amounts S_{L1} , S_{L2} , S_{L3} and S_{L4} inputted thereto from the four wheel slip amount calculating section 30 are compared respectively with the target slip amounts S_{L1}' , S_{L2}' , S_{L3}' and S_{L4}' inputted thereto from the four wheel

target slip amount calculating section 31. If any one of the slip amounts exceeds the corresponding target slip amount, the traction control judging section 32 judges a traction control to be performed on the wheel or the wheels exceeding the target slip amount and outputs a traction control signal to the four wheel target braking force calculating section 33 and the target engine torque calculating section 33. Further, if the slip amounts are less than the corresponding target slip amounts, the traction control judging section 32 judges a stop of the traction control so as to stop the traction control when brake pressures for the four wheels become zero and the engine output restores a normal operational condition and outputs a stop signal of the traction control to the four wheel target braking force calculating section 33 and the target engine torque calculating section 35.

The four wheel target braking force calculating section 33, when the traction control is applied to the subject wheel or wheels, calculates a target braking force (a target brake pressure) for each wheel, BF1, BF2, BF3 and BF4 according to the difference between the actual slip amount S_{L1} , S_{L2} , S_{L3} , S_{L4} and the target slip amount S_{L1}' , S_{L2}' , S_{L3}' and S_{L4}' and outputs the target braking force (target brake pressure) to the brake signal outputting section 34.

The brake signal outputting section 34 outputs to the brake drive apparatus 16 a brake signal so as to apply the target brake pressure BF1, BF2, BF3 and BF4 which have

been calculated in the four wheel target braking force calculating section 33 to the corresponding wheel.

The target engine torque calculating section 35, when the traction control is applied to the subject wheel or wheels, compares the slip amount with the target slip amount with respect to a wheel having a highest wheel speed among the subject wheels and establishes a target engine torque T_q when the engine output is reduced by the difference of the slip amount and the target slip amount. The established torque T_q is outputted to the engine control section 15.

Next, an operation of the traction control system will be described with reference to a flowchart in Fig. 6.

When the program starts, at a step 101 (hereinafter referred to as S something) the wheel speed ω_1 , ω_2 , ω_3 and ω_4 is detected by the wheel speed sensor 20_{fl}, 20_{fr}, 20_{rl} and 20_{rr} respectively. Then, the program goes to S102 where the vehicle speed calculating section 26 calculates a vehicle speed V based on the wheel speed ω_1 , ω_2 , ω_3 and ω_4 . Then, at S103 the four wheel slip amount calculating section 30 obtains an actual slip amount S_{L1} , S_{L2} , S_{L3} , S_{L4} by subtracting the vehicle speed V from the wheel speed ω_1 , ω_2 , ω_3 , ω_4 . After that, the program goes to S104 where the four wheel target slip amount determining section 31 determines a target slip amount S_{L1}' , S_{L2}' , S_{L3}' , S_{L4}' for each wheel based on the vehicle speed V , the yaw rate r and the yaw rate deviation Δr by referring to the target slip amount

maps and steps to S105.

At S105, the traction control judging section 32 judges whether or not the traction control is needed by comparing the slip amount S_{L1} , S_{L2} , S_{L3} , S_{L4} with the target slip amount S_{L1}' , S_{L2}' , S_{L3}' , S_{L4}' . For example, when the four wheels run on a road surface having high friction coefficient and drive forces of four wheels are not higher than necessary, each of the four tyres has sufficient grip to grasp the load surface with a small amount of slip. In such a situation, since the slip amounts S_{L1} , S_{L2} , S_{L3} and S_{L4} are smaller than the target slip amounts S_{L1}' , S_{L2}' , S_{L3}' and S_{L4}' respectively, there is no need for traction control and the program goes to an end.

On the other hand, when the vehicle driver presses an accelerator pedal excessively on a road with a surface having high friction coefficient or when the vehicle runs on a road with a surface having low friction coefficient, wheel slips tend to occur because of the drive force coming close to the limit of friction coefficient of the road surface. In this situation, since any of the slip amounts S_{L1} , S_{L2} , S_{L3} and S_{L4} exceeds any corresponding one of the target slip amounts S_{L1}' , S_{L2}' , S_{L3}' and S_{L4}' , it is judged that the traction control is needed and the program steps to S106.

At S106, the four wheel target braking force calculating section 33 calculates a difference between the

slip amount S_{L1} , S_{L2} , S_{L3} , S_{L4} and the target slip amount S_{L1}' , S_{L2}' , S_{L3}' , S_{L4}' of the wheel needing the traction control and produces a target brake pressure BF1, BF2, BF3, BF4. The target brake pressure is outputted to the brake drive apparatus 16 through the brake signal outputting section 34 so as to apply the target brake pressure BF1, BF2, BF3, BF4.

Further, the program goes to S107 where the target engine torque calculating section 35 compares the slip amount with the target slip amount with respect to the wheel having the highest wheel speed and determines the target engine torque T_q lowered by the difference between the slip amount and the target slip amount. The target engine torque T_q thus determined is outputted to the engine control apparatus 15.

The applied brake pressure and the reduced engine output control the traction of the four wheels so as to reduce slip amounts, whereby excessive slip of wheels can be prevented.

When the vehicle driver operates the accelerator pedal so as to lower the engine output, the slip amount is decreased immediately and brake pressures of the four wheels drop to zero. At this moment, it is judged that the traction control is not needed and the vehicle returns to a normal four-wheel drive operation.

Next, referring to Fig. 7, the program for determining the target slip amount will be described. First, at

S201, the steering wheel angle $\hat{\theta}$ is read from the steering wheel sensor 21, the wheel speed $\omega_1, \omega_2, \omega_3, \omega_4$ is read from the wheel speed sensor $20_{fl}, 20_{fr}, 20_{rl}, 20_{rr}$, and the actual yaw rate γ is read from the yaw rate sensor 22.

Then, the program goes to S202 where the steering angle calculating section 27 calculates the actual steering angle $\delta f (= \theta / N)$ from the steering wheel angle θ and the vehicle speed calculating section 26 calculates the vehicle speed V from the wheel speed $\omega_1, \omega_2, \omega_3, \omega_4$ for each wheel.

Then, the program goes to S203 where the target yaw rate calculating section 28 calculates the target yaw rate γ' according to the formula (1) and after that at S204 the yaw rate deviation calculating section 29 calculates the yaw rate deviation $\Delta\gamma (= \gamma - \gamma')$.

Then, the program steps to S205 where it is judged whether or not the actual yaw rate γ is larger than ε , that is to say, whether or not the vehicle is making a relatively sharp left turn and if the actual yaw rate γ is less than ε the program goes to S206 where it is judged whether or not the actual yaw rate γ is smaller than $-\varepsilon$, that is to say, whether or not the vehicle is making a relatively sharp right turn. If at S206 it is judged to be $\varepsilon \geq \gamma \geq -\varepsilon$, since it can be judged that the vehicle is making neither a left turn nor a right turn, namely since it can be judged that the vehicle is running roughly in a straight line, the program skips to t

S219 where the target slip amount map is not corrected. If at S205 it is judged that r is larger than ε ($r > \varepsilon$), the program goes to S207 where it is judged whether or not the yaw rate deviation Δr is near zero according to the formula of inequality $|\Delta r| \leq |\varepsilon \Delta r|$ to judge whether or not the vehicle is in a roughly neutral steer.

Further, at S207 if $|\Delta r| \leq |\varepsilon \Delta r|$, namely, it is judged that the actual yaw rate r is roughly equal to the target yaw rate r' (in a roughly neutral steer), the program steps to S219 and if otherwise (in an under-steer tendency or in an over-steer-tendency), the program goes to S208.

The step S208 is a step where it is judged whether or not the vehicle is either in an under-steer tendency or in an over-steer tendency. At S208 if $\Delta r < -\varepsilon \Delta r$ and the sign of the yaw rate deviation Δr is negative differently from the sign of the actual yaw rate r , it is judged that the vehicle is in an under-steer tendency with respect to the target yaw rate r' and the program steps to S209 and if $\Delta r > \varepsilon \Delta r$, the sign of the yaw rate Δr is positive similarly to the sign of the actual yaw rate r , it is judged that the vehicle is in an over-steer tendency with respect to the target yaw rate r' and the program goes to S211.

When the program goes to S209, the target slip amount of the left front wheel is corrected to the lower side and at S210 the target slip amount of the right rear wheel is corrected to the higher side. Further, when the program goes

to S211, the target slip amount of the left front wheel is corrected to the higher side and at S212 the target slip amount of the right rear wheel is corrected to the lower side.

On the other hand, at S206 if it is judged that the yaw rate γ is less than $-\varepsilon$ ($\gamma < -\varepsilon$), that is, if it is judged that the vehicle is making a relatively sharp right turn, the program steps to S213 where it is judged whether or not the yaw rate deviation $\Delta\gamma$ is near zero according to the formula of inequality $|\Delta\gamma| \leq |\varepsilon\Delta\gamma|$ and the actual yaw rate γ roughly agrees with the target yaw rate γ' .

At S213, if $|\Delta\gamma| \leq |\varepsilon\Delta\gamma|$ and the actual yaw rate γ is roughly equal to the target yaw rate γ' , the program goes to S219 where no correction is made to the target slip amount. If otherwise (either in an under-steer tendency or in an over-steer tendency), the program goes to S214.

The step S214 is a step where it is judged whether the vehicle is in an under-steer tendency or in an over-steer tendency according to $\Delta\gamma > \varepsilon\Delta\gamma$ or $\Delta\gamma < -\varepsilon\Delta\gamma$. If $\Delta\gamma > \varepsilon\Delta\gamma$ and the sign of the yaw rate deviation $\Delta\gamma$ is positive differently from the sign of the actual yaw rate γ , it is judged that the vehicle is in an under-steer tendency with respect to the target yaw rate γ' and then the program goes to S215. On the other hand, if $\Delta\gamma < -\varepsilon\Delta\gamma$ and the sign of the yaw rate deviation $\Delta\gamma$ is negative similarly to the sign

of the actual yaw rate γ , it is judged that the vehicle is in an over-steer tendency with respect to the target yaw rate γ' and then the program goes to S217.

When the program goes to S215, the target slip amount of the right front wheel is corrected to the lower side and at S216 the target slip amount of the left rear wheel is corrected to the higher side. Further, when the program goes to S217, the target slip amount of the right front wheel is corrected to the higher side and at S218 the target slip amount of the left rear wheel is corrected to the lower side.

As described above, the target slip amount on the map is corrected according to the turning direction and the steer tendency of the vehicle. When any of the actual slip amounts of the four wheels exceeds the corresponding target slip amount as mentioned above, the traction control is carried out. According to the present invention, whenever it is judged that the traction control is needed, even when the vehicle is running in a straight line, the traction control including the brake and torque controls is applied to the vehicle.

In summary, according to the present invention, since the target slip amount is determined independently for each of four wheels so as to produce an appropriate yaw moment, the vehicle can be prevented from causing excessive slips and the vehicle stability during cornering can be enhanced.

While the presently preferred embodiment of the present invention has been shown and described, it is to be understood that this disclosure is for the purpose of illustration and that various changes and modifications may be made without departing from the scope of the invention.

- 24 -
CLAIMS

1. A traction control system for a four-wheel drive vehicle having an engine, an engine control apparatus for controlling an output torque of said engine, four wheels including front and rear wheels, a wheel cylinder for each of said four wheels, wheel speed detecting means for detecting a wheel speed of said each wheel, vehicle speed detecting means for detecting a vehicle speed, steering angle detecting means for detecting a steering angle, and a brake drive apparatus for independently and automatically applying brake pressure to said wheel cylinders, comprising:

yaw rate detecting means for detecting an actual yaw rate of said vehicle;

target yaw rate calculating means for calculating a target yaw rate of said vehicle based on said vehicle speed and said steering angle;

yaw rate deviation calculating means for calculating a yaw rate deviation by subtracting said target yaw rate from said actual yaw rate;

slip amount calculating means for calculating an actual slip amount for said each wheel based on said vehicle speed and said wheel speed;

storing means for memorizing a reference slip amount for each of said front and rear wheels respectively;

target slip amount determining means for independently determining a target slip amount for said each wheel

based on said reference slip amount, said vehicle speed, said actual yaw rate and said yaw rate deviation;

traction control judging means for judging whether or not a traction control is needed for said each wheel based on the comparison of said slip amount with said target slip amount and for outputting a traction control signal so as to execute said traction control if it is judged that any one of said four wheels needs said traction control;

target braking force calculating means responsive to said traction control signal for calculating a target brake pressure based on said actual slip amount and said target slip amount and for outputting said target brake pressure to said brake drive apparatus so as to apply said target brake pressure to said wheel cylinder of said wheel needing said traction control; and

target engine torque calculating means responsive to said traction control signal for calculating a target engine torque based on said actual slip amount and said target slip amount and for outputting said target engine torque to said engine control apparatus so as to reduce said output torque of said engine.

2. A traction control system as claimed in claim 1, wherein

said target slip amount determining means determine said target slip amount by making at least either a

correction of reducing said reference target slip amount of a front wheel on a turning centre side or a correction of increasing said target slip amount of a rear wheel on an opposite side of said turning centre when said actual yaw rate and said yaw rate deviation have a different sign from each other and determine said target slip amount by making at least either a correction of increasing said reference slip amount of said front wheel on said turning centre side or a correction of reducing said target slip amount of said rear wheel on said opposite side of said turning centre when said actual yaw rate and said yaw rate deviation have an identical sign to each other.

3. A traction control system as claimed in claim 1 or claim 2, wherein

said reference slip amount is a slip amount obtained when said vehicle is operated roughly in a straight running condition or turns almost in a neutral steer condition.

4. A traction control system as claimed in any of claims 1 to 3, wherein

said reference slip amount is predetermined in such a way that it is low at low speeds and becomes high at intermediate or higher speeds as said vehicle speed increases.

5. A traction control method for a four wheel drive vehicle having an engine, an engine control apparatus for controlling an output torque of said engine, four wheels including front and rear wheels, a wheel cylinder for each of said four wheels, wheel speed detecting means for detecting a wheel speed of said each wheel, vehicle speed detecting means for detecting a vehicle speed, steering angle detecting means for detecting a steering angle, and a brake drive apparatus for applying brake pressure to said wheel cylinder, comprising the steps of:

 detecting an actual yaw rate of said vehicle;

 calculating a target yaw rate of said vehicle based on said vehicle speed and said steering angle;

 calculating a yaw rate deviation by subtracting said target yaw rate from said actual yaw rate;

 calculating an actual slip amount for said each wheel based on said vehicle speed and said wheel speed;

 memorizing a reference slip amount for each of said front and rear wheels respectively;

 determining a target slip amount for said each wheel based on said reference slip amount, said vehicle speed, said actual yaw rate and said yaw rate deviation;

 judging whether or not a traction control is needed for said each wheel based on the comparison of said slip amount with said target slip amount and outputting a

traction control signal so as to execute said traction control if it is judged that any one of said four wheels need said traction control;

calculating a target brake pressure based on said actual slip amount and said target slip amount in response to said traction control signal and outputting said target brake pressure to said brake drive apparatus so as to apply said target brake pressure to said wheel cylinder of said wheel needing said traction control; and

calculating a target engine torque based on said actual slip amount and said target slip amount in response to said traction control signal and outputting said target engine torque to said engine control apparatus so as to reduce said output torque of said engine.

6. A traction control method as claimed in claim 5, wherein said target slip amount is determined by making at least either a correction of reducing said reference target slip amount of a front wheel on a turning centre side or a correction of increasing said target slip amount of a rear wheel on an opposite side of said turning centre when said actual yaw rate and said yaw rate deviation have a different sign from each other and said target slip amount is determined by making at least either a correction of increasing said reference slip amount of said front wheel on said

turning centre side or a correction of reducing said target slip amount of said rear wheel on said opposite side of said turning centre when said actual yaw rate and said yaw rate deviation have an identical sign to each other.

7. A traction control method as claimed in claim 5 or claim 6, wherein

said reference slip amount is a slip amount obtained when said vehicle is operated roughly in a straight running condition or turns almost in a neutral steer condition.

8. A traction control method as claimed in any of claims 5 to 7, wherein

said reference slip amount is predetermined in such a way that it is low at low speeds and becomes high at intermediate or higher speeds as said vehicle speed increases.

9. A traction control system for a four-wheel drive vehicle, substantially as herein described, with reference to, and as illustrated in, the accompanying drawings.

10. A traction control method for a four-wheel drive vehicle, substantially as herein described, with reference to, and as illustrated in, the accompanying drawings.

11. A four wheel drive vehicle comprising a traction control system as claimed in any of claims 1

to 4 and 9 or operating in accordance with a traction control method as claimed in any of claims 5 to 8 and 10.



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Claims searched: 1-11

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Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.O): F2F FA FC G3N NGA2

Int Cl (Ed.6): B60T 8/00 B60K 41/20

Other: Online:EDOC,WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
A	GB 2297633 A (Fuji Jukogyo)	
A	EP 0321894 A2 (Fuji Jukogyo)	
A	US 4849891 (Daimler-Benz)	

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